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Abstract

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SOME RESULTS OF SPECTROPHOTOMETRY OF THE EARTH FROM THE "SOYUZ-7" SPACECRAFT

The first experiment on spectrophotometry of the twilight halo of the Earth from space was carried out in January 1969 during the flight of the "Soyuz-5" spacecraft. The principal results of this experiment are presented in papers ($^{1-4}$). During the group flight of the spacecraft "Soyuz-6, 7, 8," the program of the comprehensive optical experiment was expanded and provided for solving the following main problems:

1. Spectrophotometry of the Sun and of the twilight halo of the Earth' s atmosphere under different conditions of viewing, solar illumination, and the observer' s position in space, in order to investigate the brightness and color pattern of the halo and to study the vertical distribution of various components of the atmosphere.
2. Spectrophotometry of various natural formations with the aim of studying the possibilities of their identification from spectral reflectance characteristics measured from space.
3. Synchronous execution of a comprehensive program of ground-based and airborne optical studies of the atmosphere and of various types of underlying surfaces in the subsatellite zone, in order to obtain data characterizing the spectral transmission function of the atmosphere, and the spectra and spectral contrasts of natural formations as functions of the basic optical parameters.

Spectrophotometry of the twilight atmosphere and of underlying surfaces from the "Soyuz-7" spacecraft was carried out using a modified hand-held spectrograph RSS-2 (^{5}), whose input teleobjective (focal length $f = 135$ mm, relative aperture $D/f = 1 : 4$) simultaneously focuses the image of the distant object being spectrophotometered onto the entrance slit of the spectrograph (the spectrograph channel) and directly onto the photographic film (the photo-reference channel). For this spectrograph design the linear dispersion is 166 Å/mm, the spectral slit width is 50 Å, and the spectral measurement range is 430–690 mμ. The limiting angular resolution of the spectrograph channel is 2′, and that of the photo-reference channel 4′. The spectra were processed according to the procedure described in ([4]).

In the preceding experiment ([1]) the effect of the spectral transmission of solar radiation through the spacecraft window was not evaluated. To estimate this quantity, a light-scattering filter with known optical characteristics was installed in front of the spectrograph objective, after which the instrument was pointed at the Sun.

Comparison of the densities of the photographic-film blackening in the spectrograph, obtained from the standard source and from the Sun when using the above-mentioned light-scattering filter, makes it possible to determine the spectral irradiance of a unit area produced by solar radiation after passing through the spacecraft window.

During the group flight of the spacecraft "Soyuz-6, 7, 8," spectrophotometry of the twilight halo was carried out on the 87th orbit of the cosmi-

spacecraft "Soyuz-7" at 21 hr 41 min Moscow time as the Sun was setting. The geographic coordinates of the spacecraft "Soyuz-7" at the moment of the experiment were: 23.18° N and 23.39° E (the region of northeastern Africa). The orbital altitude at the time of the experiment was approximately 218 km.

Comparison of the results obtained with the data from an analogous experiment carried out during the flight of the spacecraft "Soyuz-5" shows that the qualitative behavior of the monochromatic brightness curves of the halo is the same in both experiments. However, the absolute brightness values in the preceding experiment (⁀1) were 2–3 times smaller ($\lambda = 650$ mμ). As in the previous experiment (⁀4), the monochromatic brightness curves show no noticeable depressions caused by aerosol layers localized at different levels in the atmosphere.

Fig. 1. Curves of spectral brightness B, $(\mathrm{W/m^2 \cdot m\mu \cdot sterad}) \cdot 10$, of natural surfaces obtained on 13 October 1969 during the flight of the manned spacecraft "Soyuz-7" . *a*—from the spacecraft: **1**—dense cloud cover, **2, 3**—thin cloud cover, **4**—desert surface in the northern part of the Arabian Peninsula, **5**—desert surface on the Ust-Urt plateau near the eastern shore of the Caspian Sea; *b*—from an aircraft: **1**—dense cloud cover, **2**—thin cloud cover, **3**—sands, **4**—solonchaks, **5**—stony deserts crossed by dirt roads, **6, 7**—stony deserts.

This report also presents data on the spectra of various natural surfaces obtained on 13 October 1969 from the spacecraft "Soyuz-7" along the track from the Arabian Peninsula to the Aral Sea. Spectrophotometry of different portions of the Earth' s surface was carried out during a short time interval, from 13 hr 19 min to 13 hr 29 min Moscow time, at solar altitudes of 35–50°.

During the flight of the spacecraft "Soyuz-7," spectra were obtained for the following identified categories of natural surfaces: (1) dense cloud cover, (2) thin cloud cover, (3) stony desert, (4) cloud shadow (Fig. 1a). Continuous and dense

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Fig. 2. Curves of spectral contrasts K of natural surfaces, obtained from spectrophotometric data on 13 October during the flight of the piloted spacecraft "Soyuz-7."

Figure 2: Fig. 2. Curves of spectral contrasts K of natural surfaces, obtained from spectrophotometric data on 13 October during the flight of the piloted spacecraft "Soyuz-7."

cumulus and stratocumulus cloud cover is characterized by maximum brightness values within 0.20-0.24 $\mathrm{W/m^2} \cdot \mathrm{m}\mu \cdot$ sterad in the wavelength range from 440 to 580 mμ (Fig. 1a, 1). A noticeable decrease in brightness to 0.14-0.15 $\mathrm{W/m^2} \cdot \mathrm{m}\mu \cdot$ sterad occurs in the orange-red part of the spectrum at λ = 580-690 mμ. Thin cloud cover of altostratus and stratocumulus forms at different levels gives an integral image both of the cloud layer and of the translucent shaded surface. The latter does not substantially change the spectral course of the brightness, but strongly reduces its absolute values to 0.12-0.14 $\mathrm{W/m^2} \cdot \mathrm{m}\mu \cdot$ sterad in the interval λ = 440-580 mμ and to 0.07-0.10 $\mathrm{W/m^2} \cdot \mathrm{m}\mu \cdot$ sterad in the interval λ = 580-690 mμ (Fig. 1a, 2, 3).

The stony desert of the Ustyurt plateau is composed of limestones and is covered with gray-brown loamy-rubbly soils, in places with takyrs and thin silty-sandy deposits. The vegetation cover is sparse and has no appreciable effect on the spectra of the landscapes. Underlying surfaces of this kind yield spectral-brightness curves

Fig. 2. Curves of spectral contrasts K of natural surfaces, obtained from spectrophotometric data on 13 October during the flight of the piloted spacecraft "Soyuz-7." *a* —from the spacecraft: 1 —dense cloudiness —desert (Arabia); 2 —dense cloudiness —desert (Ustyurt); 3 —thin cloudiness —desert (Ustyurt), 4 —dense cloudiness —thin cloudiness, 5 —thin cloudiness —desert (Arabia), 6 —illuminated desert (Arabia) —desert (Ustyurt), 7 —illuminated desert —partially

shadowed desert (Ustyurt). *b* —from an aircraft: 1, 2 —dense cloudiness —stony desert, 3 —dense cloudiness —loamy-rubbly desert crossed by roads, 4 —dense cloudiness —loamy-rubbly desert, 5, 6 —loamy-rubbly desert crossed by roads — stony desert, 7 —loamy-rubbly desert —loamy-rubbly desert crossed by roads, 8 —loamy-rubbly desert —stony desert, 9 —two areas of stony desert on the Ustyurt plateau.

with very weakly expressed changes in intensity across the spectrum, within the limits of 0.05-0.07 watt/m^2 · mμ · sterad (Fig. 1*a*, 4, 5).

Finally, it is of interest to analyze the darkest type of spectrophotometered surface—areas of noncontinuous shadow from cloudiness. Since the shadows were noncontinuous, they gave brightness values much lower than those of stony deserts (0.04-0.05 watt/m^2 · mμ · sterad), and these differences are noticeably smaller in the blue-green region of the spectrum than in the red-orange.

Spectral contrasts were calculated from the above data on spectral brightnesses for all possible combinations of natural surfaces (Fig. 2*a*).

The spectral contrasts of dense cloudiness and the partially shadowed surface of the stony desert attain maximum values $k = 0.77$ at $\lambda = 630$ mμ. This contrast decreases somewhat in the blue-green region, where $k = 0.62$. The spectral contrasts of dense cloudiness and stony desert also give high absolute values of k within the limits 0.6–0.7. The changes in the contrasts are either even along the whole curve or decrease in the short-wavelength part of the spectrum (Fig. 2*a*, 1, 2). The spectral contrasts of thin cloudiness and stony desert have an analogous course of bright-

however, the absolute contrast values decrease to ~ 0.4 (Figs. 2a, 3, 5). Moderate contrast values are given by dense and thin cloud cover (Figs. 2a, 4). The course of the curve is monotonic, with variations of k within the range 0.40–0.45. The spectral contrasts of illuminated and shaded stony desert are also small ($k \approx 0.3$); moreover, they decrease noticeably in the short-wavelength region of the spectrum and increase in the long-wavelength region (Figs. 2a, 6). The contrasts between distant areas of stony desert are the smallest, $k = 0.05$–0.15 (Figs. 2a, 7), with an increase in contrasts noticeable both in the green-blue region of the spectrum at $\lambda = 520$ mμ, and in the red at $\lambda = 660$ mμ.

The results presented above were compared with synchronous aircraft measurements of brightnesses and contrasts obtained with analogous apparatus (RSS-2) over the Ustyurt Plateau in the region of the "rendezvous point" of the spacecraft and the research aircraft. Spectrophotometry from the satellite was carried out from an altitude of 220 km, and from the aircraft at approximately 2.7 km. Comparison of the results of satellite (Figs. 1a, 2a) and aircraft (Figs. 1b, 2b) measurements of the spectral brightnesses and contrasts of the same types of underlying surfaces shows that the influence of haze on the optical characteristics, as compared with measurements from an altitude of 2.7 km, is relatively small. As was to be expected, the effect of haze is noticeable in the short-wavelength region of the spectrum. In the long-wavelength range, scattering of solar radiation by the atmosphere located above 2.7 km has a very weak effect on the absolute values of the brightnesses of natural surfaces.

In conclusion it should be noted that the course of the spectral brightnesses of natural surfaces makes it possible to differentiate certain types of natural formations from spectra measured from a spacecraft. At the same time, it should be emphasized that the atmosphere distorts the course of the spectral-brightness curves and reduces spectral contrasts. However, the optical thickness of the Earth' s cloudless atmosphere is not very large; therefore, on the basis of the totality of data on reflectivity, radiation temperature, and the complex of other reflective and emissive characteristics of the underlying surfaces, a sufficiently fine differentiation of natural formations by their spectra is, in principle, possible.

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Note: Figure translations are in progress. See original paper for figures.